

# Optical spectroscopy of BL Lacertae objects. Broad lines, companion galaxies and redshift lower limits.

B. Sbarufatti<sup>1</sup>, R. Falomo<sup>2</sup>, A. Treves<sup>1</sup>, and J. Kotilainen<sup>3</sup>

<sup>1</sup> Università dell'Insubria, Via Valleggio 11, I-22100 Como, Italy

<sup>2</sup> INAF, Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy

<sup>3</sup> Tuorla Observatory, University of Turku, Väisäläntie 20, FIN-21500 Piikkiö, Finland

Received / Accepted

## ABSTRACT

**Aims.** We present optical spectroscopy of a sample of BL Lac objects, to determine their redshift, to study their broad emission line properties and to characterize their close environment.

**Methods.** Twelve objects were observed using the ESO 3.6m and the NOT 2.5m telescopes, obtaining spectra for the BL Lacs and for nearby sources.

**Results.** For seven objects, nuclear emission lines and/or absorption lines from the host galaxy were detected. In all the four cases where absorption lines were revealed, the host galaxy has been resolved with HST or ground-based imaging. The broad H $\alpha$  luminosities (or their upper limits) of the BL Lacs are similar to those of radio-loud quasars. For two BL Lacs, spectroscopy of close companions indicates that they are at the redshift of the BL Lacs, and therefore physically associated and likely interacting. Five BL Lacs have a featureless spectrum. In these cases, we apply a new technique to derive lower limits for their redshift, which are consistent with lower limits deduced from imaging.

**Key words.** BL Lacertae objects: general

## 1. Introduction.

BL Lacertae objects (hereafter BL Lacs) are a relatively rare subclass of active galactic nuclei (AGN) characterized by luminous, rapidly variable UV-to-NIR non-thermal continuum emission and polarization, strong compact flat spectrum radio emission and superluminal motion. Similar properties are observed also in flat spectrum radio quasars and these two types of AGN are often grouped together into the class of blazars. The continuum emission of BL Lacs is boosted by relativistic beaming, that depresses the equivalent width (EW) of the spectral lines. However, apart from possible fluorescent emission lines, as in other types of AGN, absorption lines from the stellar population of the host galaxy, from intervening material and from the halo of the Milky Way are expected to be present in BL Lacs. These lines are probes of the physical conditions in the source, and in the intervening medium. They are obviously the most direct way of determining or constraining the redshift of the source.

The detection of weak lines requires high S/N spectroscopy that, for most BL Lacs, translates into a necessity to use large telescopes. Until recently, most of the work in this field have made use of 2-4 m class telescopes (e.g. Falomo et al., 1993; Stickel & Kühr, 1993; Véron-Cetty & Véron, 1993; Bade, Fink, & Engels, 1994; Falomo, Scarpa, & Bersanelli,

1994; Falomo, 1996; Marchã et al., 1996; Drinkwater et al., 1997; Laurent-Muehleisen et al., 1998; Landt et al., 2001; Rector & Stocke, 2001; Londish et al., 2002; Hook et al., 2003; Carangelo et al., 2003).

However, significantly better results have been obtained with 8m class telescopes (e.g. Heidt et al., 2004; Sowards-Emmerd et al., 2005; Woo et al., 2005). In particular, a substantial step forward in the detection of faint spectral lines was achieved by our extensive study of 42 BL Lacs performed with the ESO VLT (Sbarufatti et al., 2005a, 2006, hereafter S05a and S06), where we determined the redshift for 18 sources, and developed a technique to obtain redshift lower limits for lineless sources.

In this paper, we complement the ESO-VLT dataset by observations with 2-4m class telescopes of sources that were not observed with the VLT, or that were observed in a different spectral range. The sample of 12 objects was taken from the list of BL Lacs in Padovani & Giommi (1995), selecting the brightest targets among those with no available redshift, and bright, nearby targets to search for broad emission lines (in particular H $\alpha$ ), and/or to study their environment. The first results of this campaign, concerning new redshifts, were published by Carangelo et al. (2003). Here we discuss the featureless objects, the search for broad lines and the properties of

companions of the BL Lacs. For the five lineless objects we apply a technique, developed in S06, that allows us to set lower limits to the redshift. For the four low redshift objects we report a measurement or an upper limit for the broad component of the  $H_\alpha$  emission line. In the case of 1H 0323+022 and 1ES 1440+122 we also present and discuss the spectra of their close companions. Throughout this paper, we adopt the following cosmological parameters:  $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ,  $\Omega_\Lambda = 0.7$ ,  $\Omega_m = 0.3$ .

## 2. Observations, data reduction and analysis.

In Table 1 we report a journal of the observations and in Table 2 the instrumental configurations. The low resolution setups (A, B, N) were used for the redshift determination and for studying sources in the close environment of the BL Lacs, while the medium resolution setup (C) was used for the search for the broad components of emission lines, especially  $H_\alpha$ .

**Table 2.** Instrumental configurations.

Setup	Telescope	Slit (arcsec)	Range (Å)	Disp. (Å pix <sup>-1</sup> )	Resol. (Å)
<b>A</b>	ESO 3.6 + EFOSC2	1.2	4085–7520	1.68	10.5
<b>B</b>	ESO 3.6 + EFOSC2	1.2	5200–9350	2.06	12.8
<b>C</b>	ESO 3.6 + EFOSC2	1.0	6285–8210	0.95	5.9
<b>N</b>	NOT 2.5 + ALFOSC	2.5	3200–9100	3.00	32.4

Data reduction was performed using IRAF<sup>1</sup> (Tody, 1986, 1993), following standard procedures for spectral analysis. This includes bias subtraction, flat fielding and removal of bad pixels. For each target, we obtained two spectra in order to get a good correction of the cosmic rays and to check for the reality of weak spectral features. The individual frames were then combined into a single average image. Wavelength calibration was performed using the spectra of a Helium/Neon/Argon lamp obtained during the same observing night, resulting in an accuracy of  $\sim 3 \text{ Å}$  (rms). From these calibrated final images we extracted the one-dimensional spectra adopting an optimal extraction algorithm (Horne, 1986) to improve the S/N.

Although this program did not require optimal photometric conditions, the sky was clear during most of the observations. This enables us to perform a spectrophotometric calibration of the data using standard stars (Oke, 1990) observed during the same nights. The ESO spectral setups B and C at wavelengths  $\lambda > 7000 \text{ Å}$  are affected by fringing. This was corrected for using flat field images taken immediately before or after the spectrum of the object, with the telescope in the same position. In the cases where such flat field images were not available, the resulting fringing pattern makes the detection of features in this spectral range very difficult, if not impossible. Finally, all the spectra were dereddened following the extinction law by Cardelli, Clayton, & Mathis (1989), and assuming the  $E_{B-V}$  values computed by Schlegel, Finkbeiner, & Davis (1998).

<sup>1</sup> IRAF (Image Reduction and Analysis Facility) is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

In Fig. 1, we present the optical spectrum of each source. In order to show more clearly the continuum shape and the faint features, we report both the flux calibrated and the normalized spectrum for each object. The main emission and absorption features are identified, interstellar absorption features are marked as ISM, and telluric absorption features as  $\oplus$ . All these spectra are electronically available in our spectroscopic library of BL Lacs, at <http://www.oapd.inaf.it/zblac/>.

### 2.1. Redshift lower limits.

For five objects the spectra appear featureless. In these cases, using the minimum observable EW ( $EW_{min}$ ), it is possible to derive a lower limit for the redshift. This procedure is described in detail in S06. Briefly, it is based on the assumption that the host galaxy is an elliptical with an absolute magnitude of  $M_R \approx -22.9 \pm 0.5$ , as derived from the analysis of a homogeneous sample of HST images of BL Lacs (see Urry et al., 2000; Sbarufatti et al., 2005b, hereafter S05b). Adopting a template for the spectrum of an elliptical galaxy (Kinney et al., 1996), it was shown by S06 that from the apparent magnitude of the BL Lac, and the  $EW_{min}$  in the spectrum, one can obtain a lower limit to the redshift. The lower limits from this procedure and their comparison with redshifts or lower limits deduced from the imaging of the host galaxy are reported in Table 3.

**Table 3.** Featureless objects.

Object name	$EW_{min}$	$z_{min}$	$z_{ima}^1$
PKS 0109+224	0.43	$>0.18$	$>0.40$
MS 0622.5-525	1.48	$>0.49$	$>0.41$
1ES 1106+244	2.5	$>0.29$	0.46
1ES 1239+069	0.75	$>0.60$	$>0.92$
PG 1437+398	0.8	$>0.24$	0.26

<sup>1</sup>: Imaging redshifts from S05b. For PKS 0109+224, see Falomo (1996).

## 3. Results for individual objects.

**PKS 0109+224** : This radio source was discovered in the 5 GHz Green Bank survey (Davis, 1971) and subsequently classified as a BL Lac by Owen & Muffson (1977). It exhibits significant variability in flux and polarization in both radio and optical bands (Ciprini et al., 2004). The host galaxy was not detected in images obtained at the NTT (Falomo, 1996) and the NOT (Nilsson et al., 2003). The claimed detection of the host by Wright et al. (1998) ( $m_K=12.2$ ) is dubious, since the host is resolved only in one of their two images. Based on the non-detection of the host and assuming that the host has an absolute magnitude  $M_R=-23.5$ , Falomo (1996) proposed a lower limit to its redshift of  $z > 0.4$ . Previous low-medium S/N optical spectra were featureless (Wills & Wills, 1979; Falomo, Scarpa, & Bersanelli, 1994). Although we reach a high S/N ( $S/N = 230$ ) in the red (5500–9000 Å), the spectrum remains featureless (Fig. 1). We determine  $EW_{min}=0.43 \text{ Å}$  which according to our adopted procedure implies a redshift

**Table 1.** Journal of observations.

Object name	RA (J2000)	Dec (J2000)	$z$	Ref. <sup>1</sup>	$m_R$ <sup>2</sup>	Setup	S/N	Exposure time (s)	Date
PKS 0109+224	01 12 05	+22 44 54	*		15.6	B	230	1800	26 Jul 01
1H 0323+022	03 26 13	+02 25 15	0.147	F86	18.4	A	30	2100	15 Jan 02
					18.4	C	30	2400	13 Jan 02
PKS 0521-36	05 22 57	-36 27 03	0.055	D79	15.1	C	90	1800	26 Jul 01
PKS 0548-322	05 50 41	-32 16 11	0.068	F76	16.4	C	50	1800	13 Jan 02
MS0622.5-5256	06 23 37	-52 57 57	*		19.2	A	20	2400	14 Jan 02
1ES 1106+244	11 09 16	+24 11 20	(0.46) <sup>3</sup>	S05b	18.7	N	15	3600	9 Mar 05
1ES 1239+069	12 41 48	+06 36 01	*		19.2	A	20	2400	25 Jul 01
PG 1437+398	14 39 18	+39 32 42	(0.26) <sup>3</sup>	S05b	16.9	N	60	3600	9 Mar 05
1ES 1440+122	14 42 48	+12 00 40	0.162	S93	17.2	A	60	2400	24 Jul 01
PKS 2005-489	20 09 25	-48 49 54	0.071	F87	13.9	A	400	2400	25 Jul 01
					13.9	C	250	2400	25 Jul 01
PKS 2155-304	21 58 51	-30 13 31	0.116	F93	13.1	A	90	2400	25 Jul 01
PKS 2201+04	22 04 18	+04 40 02	0.027	V93	15.2	C	100	1800	13 Jan 02

<sup>1</sup>: References for redshift determination:

F76: Fosbury & Disney (1976)    F87: Falomo et al. (1987)    V93: Véron-Cetty & Véron (1993)  
D79: Danziger et al. (1979)    S93: Schachter et al. (1993)    S05b: Sbarufatti et al. (2005b)  
F86: Filippenko et al. (1986)    F93: Falomo et al. (1993)

<sup>2</sup>: R-band magnitudes determined from the flux measured in our spectra.<sup>3</sup>: The imaging redshift estimate from S05b.

lower limit of  $z > 0.18$ , consistent with, but considerably lower than the limit from imaging.

**1H 0323+022** : This X-ray selected object (Doxsey et al., 1983) was classified as a BL Lac by Margon & Jacoby (1984). It exhibits significant optical polarization (Feigelson et al., 1986) and variability (Villata et al., 2000). The host galaxy was resolved in ground-based images by Feigelson et al. (1986), Falomo (1996) and Nilsson et al. (2003). The signature of the host galaxy at  $z=0.147$  was also clearly apparent in the optical spectrum of Filippenko et al. (1986). Our new spectrum (Fig. 1), despite being dominated by the strong nuclear component, clearly shows several absorption lines from the host galaxy, i.e. CaII  $\lambda\lambda 3934, 3968$  and G band  $\lambda 4305$  (setup A), and NaI  $\lambda 5892$  (setup C), confirming its redshift as  $z=0.147$ . The spectrum also reveals the narrow [NII]  $\lambda 6583$  emission line at this redshift. However, no broad H $\alpha$  emission is detected, with an EW<sub>min</sub> limit of 1 Å, corresponding to an upper limit of  $1.8 \cdot 10^{40}$  erg s<sup>-1</sup> for the broad H $\alpha$  luminosity.

This BL Lac is located in a complex environment (e.g. Falomo, 1996), as shown in Fig. 2. At a distance of  $\sim 1'$  east of the BL Lac there is a bright elliptical galaxy (G1) at a similar redshift as the BL Lac ( $z \sim 0.16$ , Falomo, 1996). In the close environment of the BL Lac, there are a number of complex emission features (Fig. 2). In particular, a compact knot-like structure (G2) is located at a distance of  $\sim 2.6''$ . We observed 1H 0323+022 using the setup A with the slit slightly shifted with respect to the nucleus, to simultaneously obtain also the spectra of G1 and G2 (Fig. 3). G1 is a bright elliptical galaxy at a redshift of  $z=0.160$ , determined from the CaII H & K, G band, and MgI absorption lines. The spectrum of G2 (Fig. 3, second panel), because of its small angular distance from the BL Lac and its low surface brightness, is contaminated by the

light from the BL Lac and its host galaxy. Therefore we extracted a spectrum using an identical aperture size to the one used for G2, taken in a position symmetric to G2 with respect to the position of the BL Lac (Fig. 3, third panel), and subtracted it from the spectrum of G2. The decontaminated spectrum of G2 (Fig. 3, bottom panel) has the characteristic shape of an elliptical galaxy, with the absorption features of CaII  $\lambda\lambda 3934, 3968$ , G band  $\lambda 4305$  and MgI  $\lambda 5175$  at  $z=0.148$ . The measured flux from the spectrum leads to an estimate of  $R \approx 18.6$ , which corresponds to  $M_R = -20.9$ . Therefore, G2 could be an elliptical dwarf galaxy at the redshift of 1H 0323+022, as already suggested by Falomo (1996). The projected distance of G2 from the BL Lac is only  $d \approx 8$  kpc.

**PKS 0521-36** : This is a well studied BL Lac which has been observed extensively at all wavelengths (see e.g. Pian et al., 1996, and references therein). The host galaxy has been resolved in several imaging studies (e.g. Wurtz et al., 1996; Falomo, Scarpa, & Bersanelli, 1994; Kotilainen et al., 1998; Urry et al., 2000; Cheung et al., 2003). The redshift of this BL Lac ( $z=0.055$ ) Danziger et al. (1979) is based on both absorption lines from the host galaxy and strong emission lines from the nucleus. In particular, a broad (FWHM  $\sim 3000$  km s<sup>-1</sup>) H $\alpha$  with varying EW (ranging from 20 to 80 Å) has been detected (Falomo, Scarpa, & Bersanelli, 1994). Our high S/N spectrum (Fig. 1) clearly shows the narrow [OII]  $\lambda 6300$ , HeI  $\lambda 5875$  and SII  $\lambda\lambda 6716, 6730$  emission lines, and the broad H $\alpha$ + [NII] blend, with EW=40.7 Å, corresponding to a broad H $\alpha$  luminosity of  $7.5 \cdot 10^{41}$  erg s<sup>-1</sup>, which is within the range previously observed by Falomo, Scarpa, & Bersanelli (1994).

**PKS 0548-322** : This X-ray selected BL Lac at  $z=0.068$  (Fosbury & Disney, 1976) is located in a rich environment

(Falomo et al., 1995). At least one of the companions shows signs of interaction with the BL Lac. The host galaxy has been detected both in imaging (Urry et al., 2000) and in spectroscopy by Falomo & Ulrich (2000), who did not reveal emission lines. Our new spectrum (Fig. 1) clearly shows a narrow emission line which we identify as [NII] $\lambda$ 6583 at  $z=0.068$ . The presence of [NII] emission could be a signature of recent star formation in the host galaxy, induced by the interaction with the close companion Falomo et al. (1995). No other emission features are detected, and the  $EW_{min}$  limit of  $0.9 \text{ \AA}$  corresponds to an upper limit of  $8.4 \cdot 10^{39} \text{ erg s}^{-1}$  for the broad  $H_\alpha$  luminosity, i.e. five times smaller than the upper limit by Falomo & Ulrich (2000).

**MS0622.5-5256** : This is an X-ray selected BL Lac belonging to the EINSTEIN Extended Medium Sensitivity Survey (EMSS, Gioia et al., 1990). Previous low S/N spectroscopy (Stocke et al., 1985) showed a featureless continuum. HST imaging of this BL Lac (Scarpa et al., 2000a) failed to resolve the host galaxy, suggesting a redshift lower limit  $z > 0.4$  (see S05b). Our new spectrum (Fig. 1) is featureless, with  $EW_{min}=1.48 \text{ \AA}$ , which gives a spectroscopic redshift lower limit of  $z > 0.49$ , well consistent with the lower limit from imaging.

**1ES 1106+244** : This BL Lac belongs to the EINSTEIN Extended Medium Sensitivity Survey (EMSS, Gioia et al., 1990). The host galaxy has been resolved both in ground-based (Falomo & Kotilainen, 1999) and in HST imaging (Urry et al., 2000), indicating a redshift lower limit of  $z \approx 0.42$ . Earlier spectroscopy of this BL Lac by Perlman et al. (1996) showed a featureless spectrum. From our moderate S/N spectrum (Fig. 1) we determine  $EW_{min}=2.50 \text{ \AA}$ , which implies a redshift lower limit of  $z > 0.29$ , consistent with the limit obtained from imaging.

**1ES 1239+069** : This high energy peaked BL Lac (HBL) has been proposed as a candidate TeV source by Stecker et al. (1996), being supposedly at a relatively low redshift ( $z=0.150$ , Perlman et al., 1996). However, this redshift estimate, based on the possible detection of absorption features from the host galaxy, is ruled out by our new spectrum (Fig. 1), from which the measured  $EW_{min}=0.75 \text{ \AA}$  implies  $z > 0.60$ . Moreover, the non-detection of the host galaxy in imaging sets a further lower limit of  $z > 0.92$  (S05b), considerably higher than the spectroscopic one, making the detection of this BL Lac in the TeV domain unlikely. Indeed Horan et al. (2004) failed to detect this BL Lac using the Whipple 10 m  $\gamma$ -ray telescope.

**PG 1437+398** : This HBL belongs to the Sedentary Survey (Giommi et al., 2005). Its host galaxy was resolved with HST imaging, giving an imaging redshift of  $z \approx 0.26$  (S05b). Previous optical spectroscopy (Laurent-Muehleisen et al., 1998; White et al., 2000; Scarpa et al., 1995) have led to a featureless spectrum. Note that the redshift  $z=0.34$  reported for this BL Lac by the NASA Extragalactic Database is based on

a very low S/N ( $\sim 5$ ) Sloan Digital Sky Survey spectrum<sup>2</sup>. This redshift is ruled out by our new, much higher S/N (S/N  $\sim 60$ ) spectrum (Fig. 1), which shows a featureless continuum. From the  $EW_{min}$  value ( $EW_{min}=0.8 \text{ \AA}$ ) we deduce a redshift lower limit of  $z > 0.24$ , consistent with the imaging redshift estimate.

**1ES 1440+122** : This is an X-ray selected BL Lac belonging to the Einstein Slew Survey. It is located in a rich environment, (Fig. 4), being surrounded by  $\sim 20$  galaxies (Heidt et al., 1999), thus suggesting that this BL Lac is located in a group or a small cluster of galaxies. The host galaxy has been resolved in several imaging studies (Heidt et al., 1999; Falomo & Kotilainen, 1999; Urry et al., 2000; Kotilainen & Falomo, 2004). High resolution HST imaging by Scarpa et al. (1999) revealed a very close companion ( $\sim 0.3''$ ) to this BL Lac, suggesting the possibility of gravitational lensing. This hypothesis was, however, ruled out by a radio-optical study by Giovannini et al. (2004) who demonstrated that the companion object is a foreground star. We obtained spectra of the BL Lac itself (Fig. 1), and of a galaxy at a distance of  $25''$  (G1) and of a close companion at a distance of  $\sim 2''$  (G2; Fig. 5). The spectrum of 1ES1440+122 is dominated by emission from the host galaxy, but the contribution of the nucleus becomes apparent towards blue wavelengths (indeed, the strength of the CaII break is only  $\sim 20\%$ ). The redshift of this BL Lac,  $z=0.162$ , measured from the CaII  $\lambda$ 3934, 3968, G band  $\lambda$ 4305 and MgI  $\lambda$ 5175 absorption lines from the host galaxy, confirms the result by Schachter et al. (1993). G1 is a typical elliptical galaxy at a redshift of  $z=0.164$ , and at a projected distance from the BL Lac of  $\sim 98$  kpc. The other companion, G2, is also an elliptical galaxy at a redshift of  $z=0.161$  (see also Nilsson et al., 2003, who discuss their unpublished spectrum of G2), and at a projected distance from the BL Lac of only  $\sim 4$  kpc. Such a small separation strongly indicates that the BL Lac and the galaxy G2 are interacting.

**PKS 2005-489** : This X-ray selected BL Lac is at low redshift ( $z=0.071$  by Falomo et al., 1987, based on the detection of  $H_\alpha$  and [NII] emission lines). More recent spectroscopy has revealed weak NI  $\lambda$ 1135 and CIII  $\lambda$ 1176 emission lines from the nucleus (Penton et al., 2004), and absorption lines from the host galaxy (Pesce et al., 1994). The host galaxy of this BL Lac, resolved in several optical and NIR imaging studies (Stickel & Kühr, 1993; Falomo, 1996; Kotilainen et al., 1998; Urry et al., 2000; Cheung et al., 2003), is a giant elliptical with  $M_R=-23.1$ , in a relatively rich environment (Pesce et al., 1994). Several of the nearby galaxies are known to be at the redshift of the BL Lac (Stickel & Kühr, 1993; Pesce et al., 1994). The optical spectrum of this BL Lac is strongly dominated by the nuclear continuum (Falomo, Scarpa, & Bersanelli, 1994; Perlman et al., 1996). The very high S/N reached by our new spectrum ( $\sim 400$ , setup A; Fig. 1) allowed the detection of the spectroscopic signatures from the host galaxy. The CaII

<sup>2</sup> see Sloan Digital Sky Survey Data Release 4, (<http://cas.sdss.org/astro/en/tools/getimg/spectra.asp>), plate 1350/52786, fiber 333, and Richards et al. (2002) for a description of the quasar survey

$\lambda\lambda 3934, 3968$ , G band  $\lambda 4305$  and MgI  $\lambda 5175$  absorption lines have EW ranging from 0.2 to 0.4 Å. The spectrum obtained with setup C confirms the presence of H $\alpha$   $\lambda 6563$  and [NII]  $\lambda 6583$  narrow emission lines. No broad component of H $\alpha$  is detected, with an EW<sub>min</sub> limit of 0.2 Å, corresponding to an upper limit of  $1.9 \cdot 10^{41}$  erg s<sup>-1</sup> for the broad H $\alpha$  luminosity.

**PKS 2155-304** : Although this HBL, a prototype of its class, has been studied in a large number of papers at all wavelengths (e.g. Pesce et al., 1997, and references therein), little optical spectroscopy has been published. Its redshift,  $z=0.116$ , has been measured by Falomo et al. (1993), from the G band, MgI and NaI absorption lines (and a marginally detected CaII doublet) in a spectrum of the host galaxy with the slit offset from the nucleus. The host galaxy has been resolved in imaging studies, with  $I=14.8$  (Falomo et al., 1991; Kotilainen et al., 1998), consistent with this redshift. Our new high S/N ESO spectrum (Fig. 1), also taken with the slit offset from the nucleus, allows us to confirm the detection of all the features reported by Falomo et al. (1993). In particular, the CaII lines  $\lambda\lambda 3934, 3968$  are clearly revealed, with EW of 0.5 and 0.4 Å for the K and H lines, respectively.

**PKS 2201+04** : This radio source was classified as a BL Lac by Weiler & Johnston (1980). Its redshift,  $z=0.026$ , proposed by Wills & Wills (1976) has been confirmed by more recent observations, showing absorption lines from the host galaxy, along with narrow and broad nuclear emission lines, in particular, broad components of H $\beta$  and H $\alpha$  (Falomo et al., 1987; Véron-Cetty & Véron, 1993). Our new spectrum (Fig. 1) reveals the [OII]  $\lambda 6300$ , [NII]  $\lambda 6583$ , H $\alpha$   $\lambda 6563$  and SII  $\lambda 6730$  emission lines. The H $\alpha$ -[NII] blend clearly shows the presence of a broad component, with an EW of 13.8 Å, corresponding to a broad H $\alpha$  luminosity of  $6.1 \cdot 10^{40}$  erg s<sup>-1</sup>.

#### 4. Conclusions.

We have presented new, high quality optical spectroscopy of a sample of 12 BL Lac objects. Absorption lines from the host galaxy were detected in four objects. In all these cases, the host galaxy has also been resolved in imaging, either with HST (1ES 1440+122, Urry et al., 2000) or from the ground (1H 0323+022, PKS 2005-489, PKS 2155-304, see Feigelson et al., 1986; Pesce et al., 1994; Kotilainen et al., 1998, respectively). The absolute magnitude of the host is in all cases close to  $M_R = -22.9$ , which is typical for BL Lac hosts (S05b). The characterization of the absorption lines from the host galaxy is, however, arduous in most cases, because the EW of the lines is strongly reduced by the beamed non-thermal continuum.

The broad emission line intensities of BL Lacs are similar to those of radio-loud quasars (e.g. Pian et al., 2005). The two cases where broad H $\alpha$  is observed in this study (PKS 0521-365,  $L_{H\alpha} \approx 7.5 \cdot 10^{41}$  erg s<sup>-1</sup>; PKS 2201+04  $L_{H\alpha} \approx 6.1 \cdot 10^{40}$  erg s<sup>-1</sup>) confirm this conclusion. It is also consistent with the derived upper limits in the cases of 1H 0323+022 ( $L_{H\alpha} < 1.8 \cdot 10^{40}$  erg s<sup>-1</sup>), PKS 0548-322 ( $L_{H\alpha} < 8 \cdot 10^{39}$  erg s<sup>-1</sup>) and PKS 2005-489 ( $L_{H\alpha} < 1.9 \cdot 10^{41}$  erg s<sup>-1</sup>).

For two BL Lacs (1H 0323+022 and 1ES 1440+122) we have demonstrated that very nearby (projected distance 4–8 kpc) companion galaxies are at the redshift of the BL Lac, indicating that there is a physical association and a likely interaction. Similar cases have been previously found for a number of other BL Lacs (see Pesce et al., 1995; Falomo, 1996; Falomo et al., 2000).

Finally, we consider the five BL Lacs which remain featureless in our spectra. Their redshift lower limits, based on the minimum observable EW of the non-detected absorption lines, appear consistent with the ones deduced from imaging. As already noted by S05b, the imaging technique is more stringent for brighter objects, but the spectral technique is the only available method for faint ( $m_V \geq 18$ ) sources.

#### References

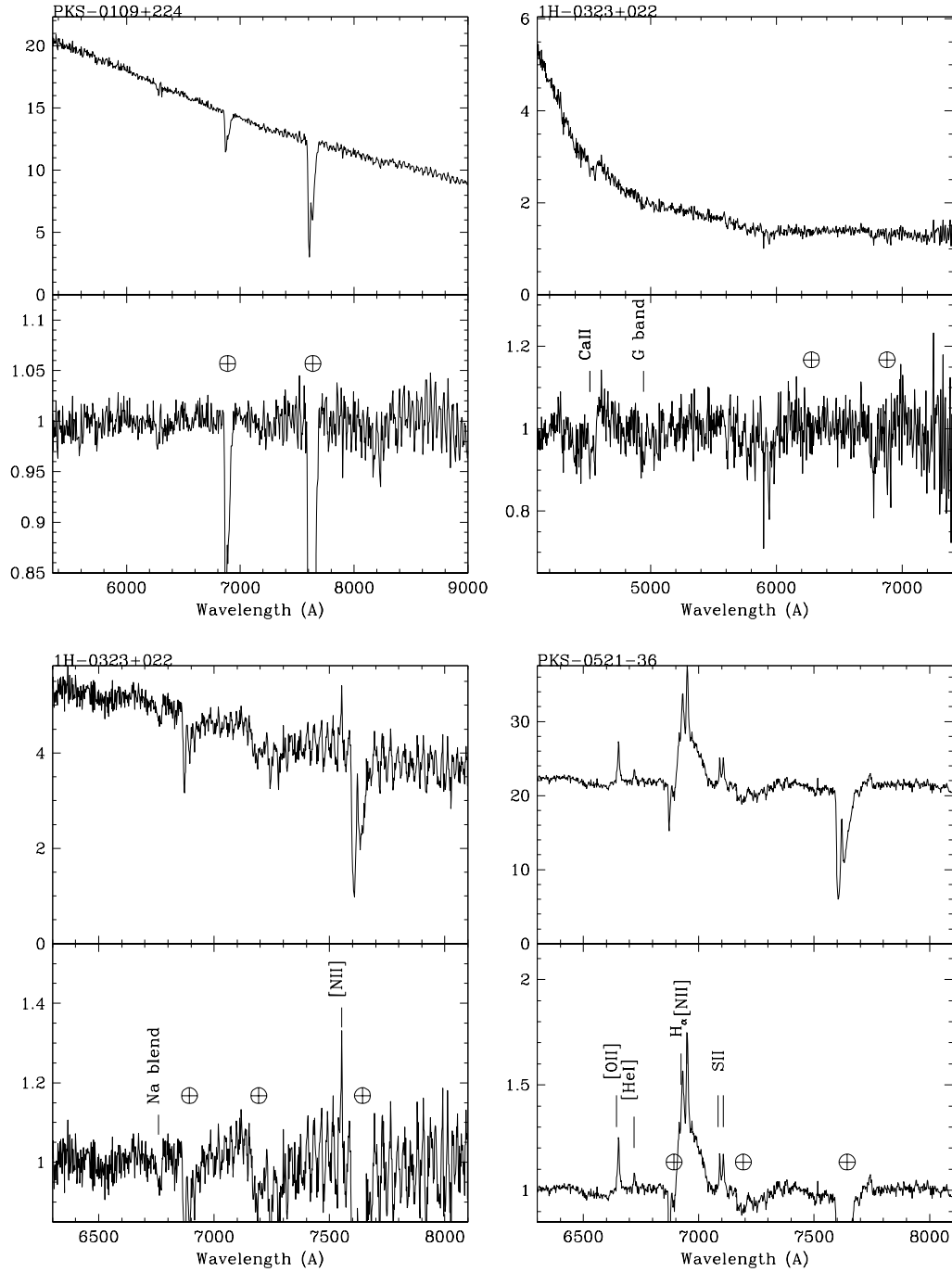
- Bade, N., Fink, H. H., & Engels, D. 1994, A&A, 286, 381
- Carangelo, N., Falomo, R., Kotilainen, J., Treves, A., & Ulrich, M.-H. 2003, A&A, 412, 651
- Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245
- Cheung, C. C., Urry, C. M., Scarpa, R., & Giavalisco, M. 2003, ApJ, 599, 155
- Ciprini, S., Tosti, G., Teräsranta, H., & Aller, H. D. 2004, MNRAS, 348, 1379
- Danziger, I. J., Fosbury, R. A. E., Goss, W. M., & Ekers, R. D. 1979, MNRAS, 188, 415
- Davis, M. M. 1971, AJ, 76, 980
- Doxsey, R., Bradt, H., McClintock, J., Petro, L., Remillard, R., Schwartz, D., Wood, K., & Ricker, G. 1983, ApJ, 264, L43
- Drinkwater, M. J., et al. 1997, MNRAS, 284, 85
- Falomo, R., Maraschi, L., Treves, A., & Tanzi, E. G. 1987, ApJ, 318, L39
- Falomo, R., Giraud, E., Melnick, J., Maraschi, L., Tanzi, E. G., & Treves, A. 1991, ApJ, 380, L67
- Falomo, R., Bersanelli, M., Bouchet, P., & Tanzi, E. G. 1993, AJ, 106, 11
- Falomo, R., Scarpa, R., & Bersanelli, M. 1994, ApJS, 93, 125
- Falomo, R., Pesce, J. E., & Treves, A. 1995, ApJ, 438, L9
- Falomo, R. 1996, MNRAS, 283, 241
- Falomo, R. & Kotilainen, J.K. 1999, A&A, 352, 85
- Falomo, R., Scarpa, R., Treves, A., & Urry, C. M. 2000, ApJ, 542, 731
- Falomo, R. & Ulrich, M.-H. 2000, A&A, 357, 91
- Feigelson, E. D., et al. 1986, ApJ, 302, 337
- Filippenko, A. V., Djorgovski, S., Spinrad, H., & Sargent, W. L. W. 1986, AJ, 91, 49
- Fosbury, R. A. E., & Disney, M. J. 1976, ApJ, 207, L75
- Gioia, I. M., Maccacaro, T., Schild, R. E., Wolter, A., Stocke, J. T., Morris, S. L., & Henry, J. P. 1990, ApJS, 72, 567
- Giommi, P., Piranomonte, S., Perri, M., & Padovani, P. 2005, A&A, 434, 385
- Giovannini, G., Falomo, R., Scarpa, R., Treves, A., & Urry, C. M. 2004, ApJ, 613, 747
- Heidt, J., Nilsson, K., Sillanpää, A., Takalo, L. O., & Pursimo, T. 1999, A&A, 341, 683

- Heidt, J., Tröller, M., Nilsson, K., Jäger, K., Takalo, L., Rekola, R., & Sillanpää, A. 2004, *A&A*, 418, 813
- Hook, I. M., Shaver, P. A., Jackson, C. A., Wall, J. V., & Kellermann, K. I. 2003, *A&A*, 399, 469
- Horan, D., et al. 2004, *ApJ*, 603, 51
- Horne, K., 1986, *PASP*, 98, 609
- Kotilainen, J. K., Falomo, R., & Scarpa, R. 1998, *A&A*, 336, 479
- Kotilainen, J. K., & Falomo, R. 2004, *A&A*, 424, 107
- Kinney, A. L., Calzetti, D., Bohlin, R. C., McQuade, K., Storchi-Bergmann, T., & Schmitt, H. R. 1996, *ApJ*, 467, 38
- Landt, H., Padovani, P., Perlman, E. S., Giommi, P., Bignall, H., & Tzioumis, A. 2001, *MNRAS*, 323, 757
- Laurent-Muehleisen, S. A., Kollgaard, R. I., Ciardullo, R., Feigelson, E. D., Brinkmann, W., & Siebert, J. 1998, *ApJS*, 118, 127
- Londish, D., et al. 2002, *MNRAS*, 334, 941
- Marchã, M. J. M., Browne, I. W. A., Impey, C. D., & Smith, P. S. 1996, *MNRAS*, 281, 425
- Margon, B., & Jacoby, G. H. 1984, *ApJ*, 286, L31
- Nilsson, K., Pursimo, T., Heidt, J., Takalo, L. O., Sillanpää, A., & Brinkmann, W. 2003 *A&A*, 400, 95
- Oke, J. B. 1990, *AJ*, 99, 1621
- Owen, F. N., & Muffson, S. L. 1977, *AJ*, 82, 776
- Padovani, P., & Giommi, P. 1995a, *MNRAS*, 277, 1477
- Pian, E., Falomo, R., Ghisellini, G., Maraschi, L., Sambruna, R. M., Scarpa, R., & Treves, A. 1996, *ApJ*, 459, 169
- Pian, E., Falomo, R., & Treves, A. 2005, *MNRAS*, 361, 919
- Penton, S. V., Stocke, J. T., & Shull, J. M. 2004, *ApJS*, 152, 29
- Perlman, E. S., et al. 1996, *ApJS*, 104, 251
- Pesce, J. E., Falomo, R., & Treves, A. 1994, *AJ*, 107, 494
- Pesce, J. E., Falomo, R., & Treves, A. 1994, *AJ*, 110, 1554
- Pesce, J. E., et al. 1997, *ApJ*, 486, 770
- Rector, T. A., & Stocke, J. T. 2001, *AJ*, 122, 565
- Richards, G. T., et al. 2002, *AJ*, 123, 2945
- Sbarufatti, B., Treves, A., Falomo, R., Heidt, J., Kotilainen, J., Scarpa, R. 2005a, *AJ*, 129, 599 (S05a)
- Sbarufatti, B., Treves, A., & Falomo, R. 2005b, *ApJ*, 635, 173 (S05b)
- Sbarufatti, B., Treves, A., Falomo, R., Heidt, J., Kotilainen, J., Scarpa, R. 2006, *AJ*, in press, astro-ph/0601506 (S06)
- Scarpa, R., Falomo, R., & Pian, E. 1995, *A&A*, 303, 730
- Scarpa, R., Urry, C. M., Falomo, R., & Treves, A. 1999, *ApJ*, 526, 643
- Scarpa, R., Urry, C. M., Falomo, R., Pesce, J. E., & Treves, A. 2000, *ApJ*, 532, 740
- Schachter, J. F., et al. 1993, *ApJ*, 412, 541
- Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, *ApJ*, 500, 525
- Sowards-Emmerd, D., Romani, R. W., Michelson, P. F., Healey, S. E., Nolan, P. L. 2005, *ApJ*, 626, 95
- Stecker, F. W., de Jager, O. C., & Salamon, M. H. 1996, *ApJ*, 473, L75
- Stickel, M., & Kühr, H. 1993, *A&AS*, 100, 395
- Stocke, J. T., Liebert, J., Schmidt, G., Gioia, I. M., Maccacaro, T., Schild, R. E., Maccagni, D., & Arp, H. C. 1985, *ApJ*, 298, 619
- Tody, D. 1986, *Proc. SPIE*, 627, 733
- Tody, D. 1993, *ASP Conf. Ser.* 52: *Astronomical Data Analysis Software and Systems II*, 2, 173
- Urry, C. M., Scarpa, R., O'Dowd, M., Falomo, R., Pesce, J. E., & Treves, A. 2000, *ApJ*, 532, 816
- Véron-Cetty, M.-P., & Véron, P. 1993, *A&AS*, 100, 521
- Villata, M., Raiteri, C. M., Popescu, M. D., Sobrito, G., De Francesco, G., Lanteri, L., & Ostorero, L. 2000, *A&AS*, 144, 481
- Weiler, K. W., & Johnston, K. J. 1980, *MNRAS*, 190, 269
- White, R. L., et al. 2000, *ApJS*, 126, 133
- Wills, D., & Wills, B. J. 1976, *ApJS*, 31, 143
- Wills, B. J., & Wills, D. 1979, *ApJS*, 41, 689
- Woo, J.-H., Urry, M. C., van der Marel, R. P., Lira, P., Maza, J., 2005, *ApJ*, 631, 762
- Wright, S. C., McHardy, I. M., Abraham, R. G., & Crawford, C. S. 1998, *MNRAS*, 296, 961
- Wurtz, R., Stocke, J. T., & Yee, H. K. C. 1996, *ApJS*, 103, 109

## List of Objects

- ‘1H 0323+022’ on page 2
- ‘1ES 1440+122’ on page 2
- ‘PKS 0109+224’ on page 2
- ‘MS 0622.5-525’ on page 2
- ‘1ES 1106+244’ on page 2
- ‘1ES 1239+069’ on page 2
- ‘PG 1437+398’ on page 2
- ‘PKS 0109+224’ on page 2
- ‘PKS 0109+224’ on page 3
- ‘1H 0323+022’ on page 3
- ‘PKS 0521-36’ on page 3
- ‘PKS 0548-322’ on page 3
- ‘MS0622.5-5256’ on page 3
- ‘1ES 1106+244’ on page 3
- ‘1ES 1239+069’ on page 3
- ‘PG 1437+398’ on page 3
- ‘1ES 1440+122’ on page 3
- ‘PKS 2005-489’ on page 3
- ‘PKS 2155-304’ on page 3
- ‘PKS 2201+04’ on page 3
- ‘1H 0323+022’ on page 3
- ‘1H 0323+022’ on page 3
- ‘1H 0323+022’ on page 3
- ‘PKS 0521-36’ on page 3
- ‘PKS 0548-322’ on page 3
- ‘MS0622.5-5256’ on page 4
- ‘1ES 1106+244’ on page 4
- ‘1ES 1239+069’ on page 4
- ‘PG 1437+398’ on page 4
- ‘1ES 1440+122’ on page 4
- ‘1ES1440+122’ on page 4
- ‘PKS 2005-489’ on page 4
- ‘PKS 2155-304’ on page 5
- ‘PKS 2201+04’ on page 5
- ‘1ES 1440+122’ on page 5
- ‘1H 0323+022’ on page 5
- ‘PKS 2005-489’ on page 5

‘PKS 2155-304’ on page 5  
‘PKS 0521-365’ on page 5  
‘PKS 2201+04’ on page 5  
‘1H 0323+022’ on page 5  
‘PKS 0548-322’ on page 5  
‘PKS 2005-489’ on page 5  
‘1H 0323+022’ on page 5  
‘1ES 1440+122’ on page 5  
‘1H 0323+22’ on page 12  
‘1H 0323+22’ on page 13  
‘1ES 1440+122’ on page 14  
‘1ES 1440+122’ on page 15



**Fig. 1.** Spectra of the BL Lacs observed with the ESO 3.6m and the NOT 2.5m telescopes. Top panel: flux calibrated spectra. Bottom panel: spectra normalized with respect to the continuum. Telluric bands are indicated by ⊕, spectral lines are marked by the line ID, and absorption features from atomic species in the interstellar medium of our galaxy are labeled by ISM.

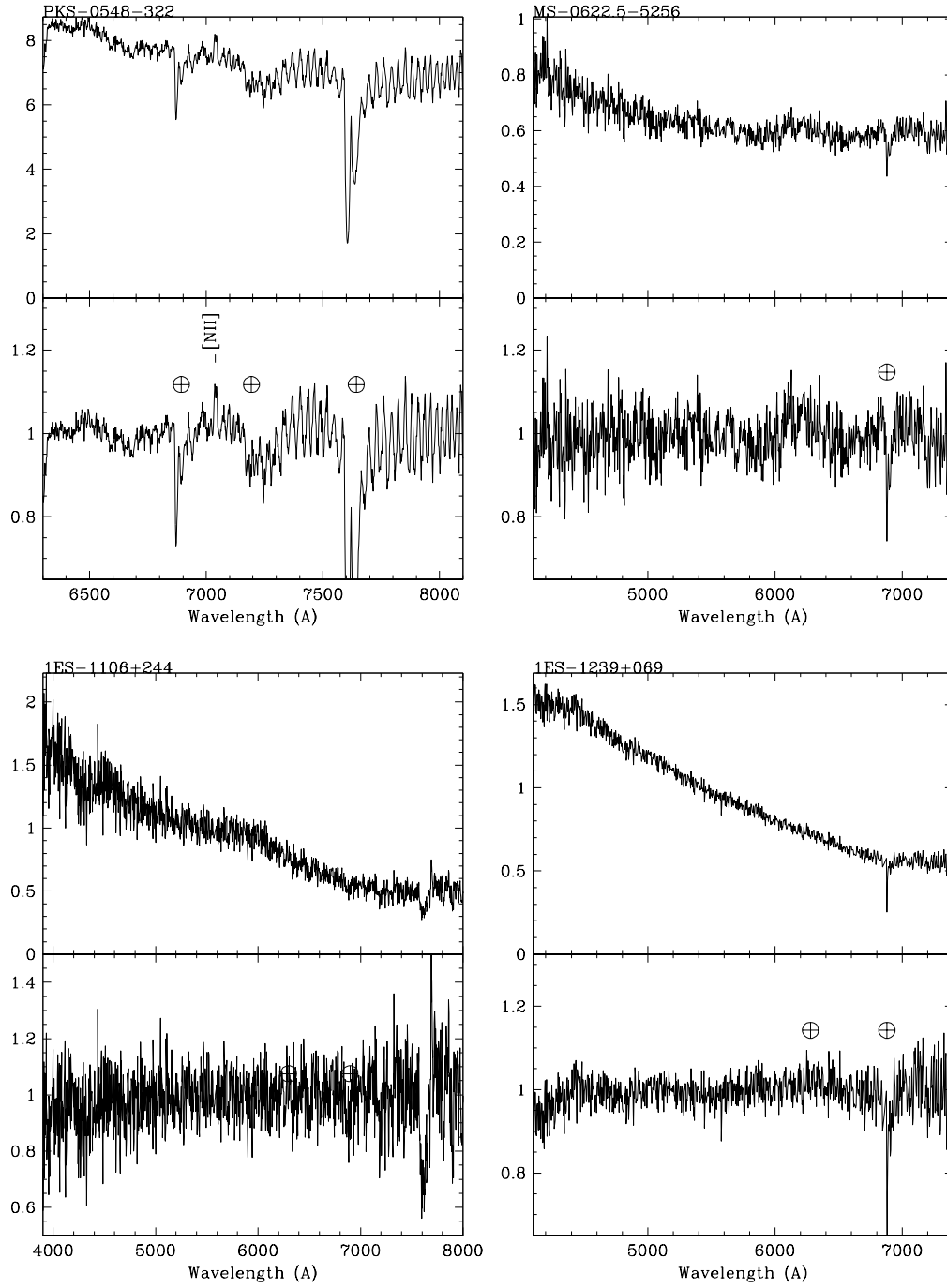


Fig. 1. continued

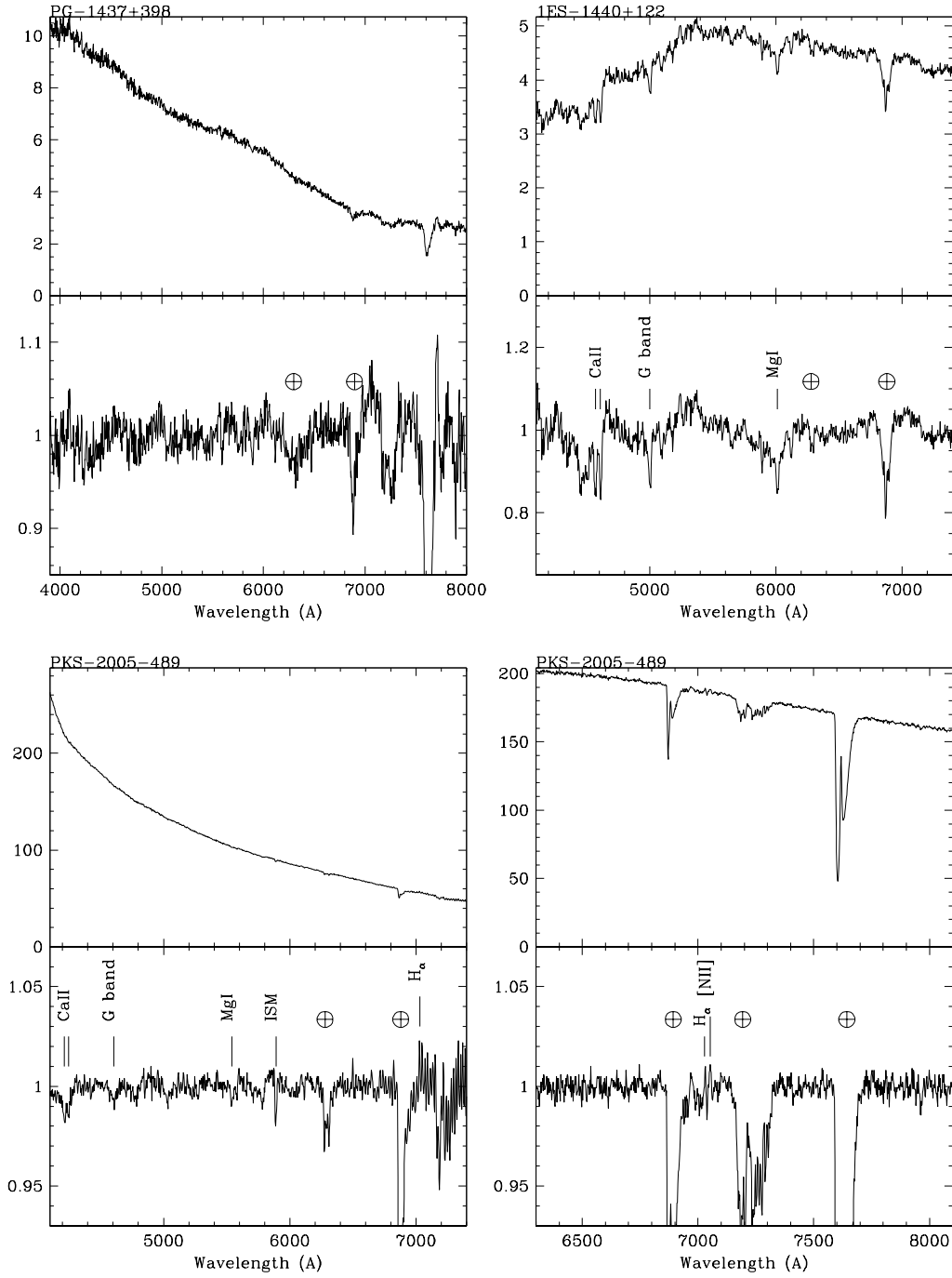


Fig. 1. continued

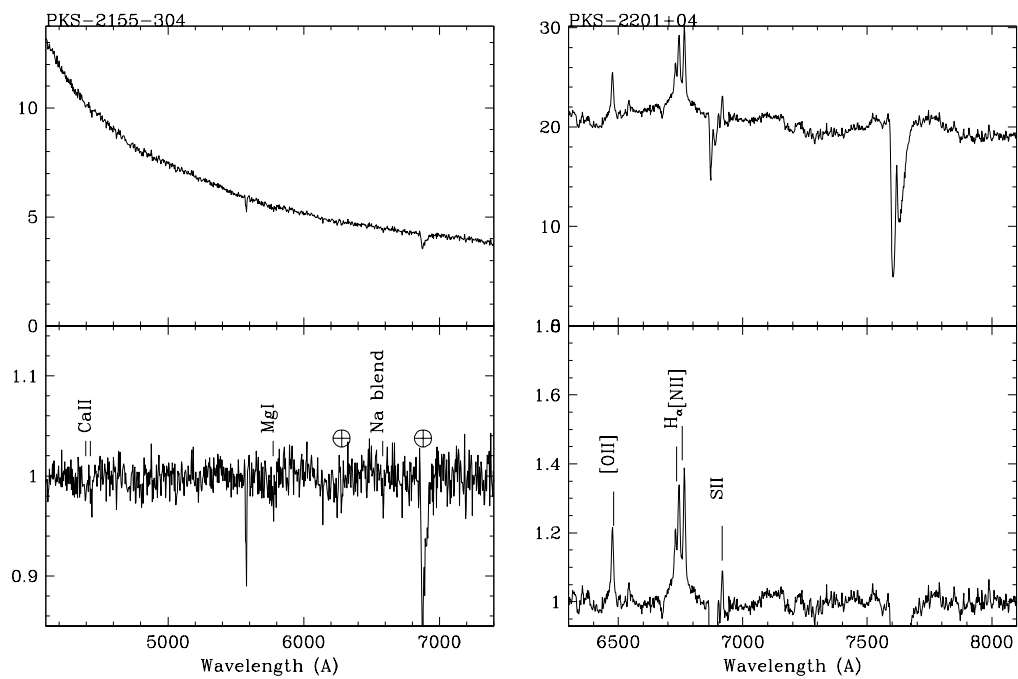
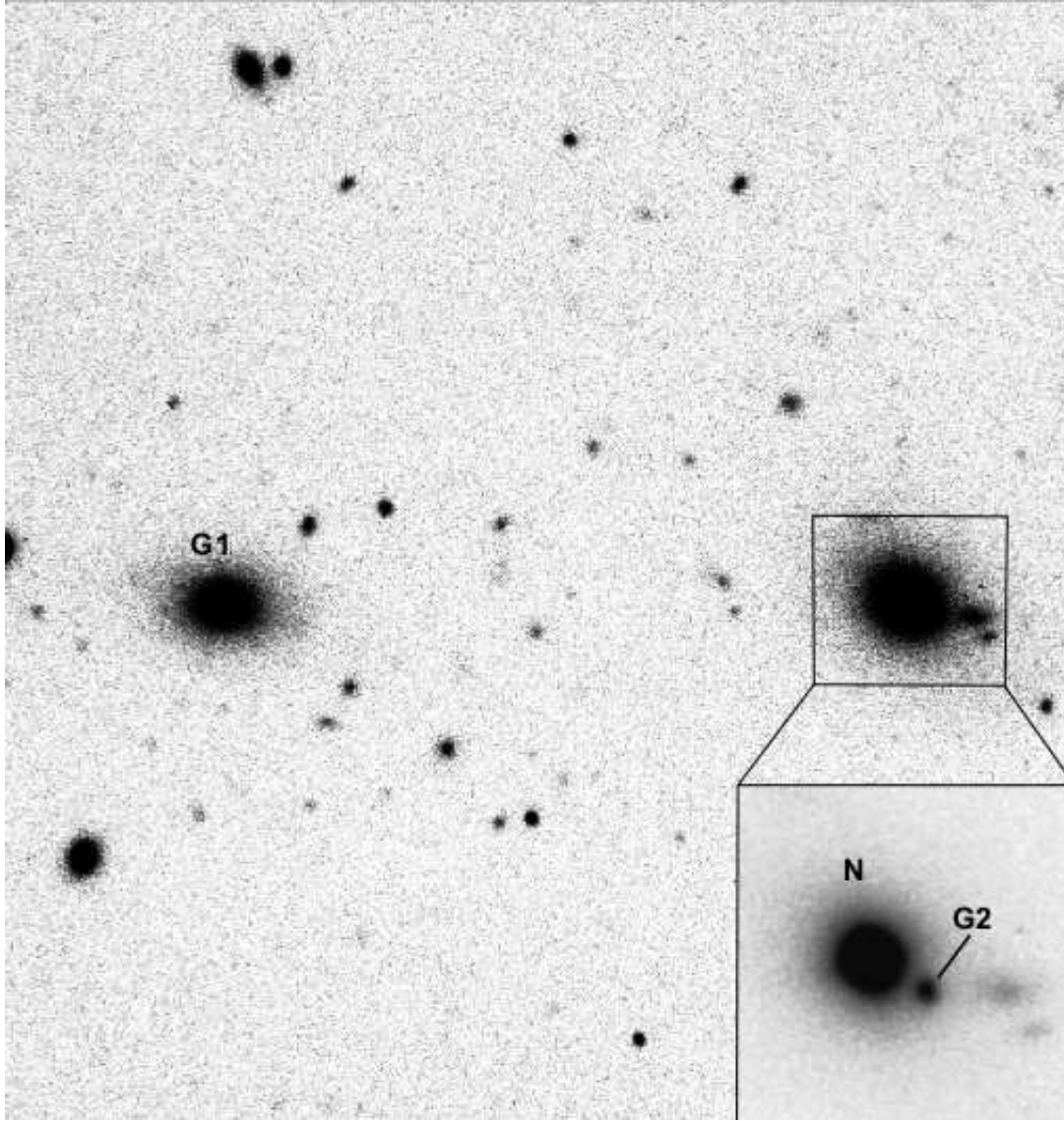
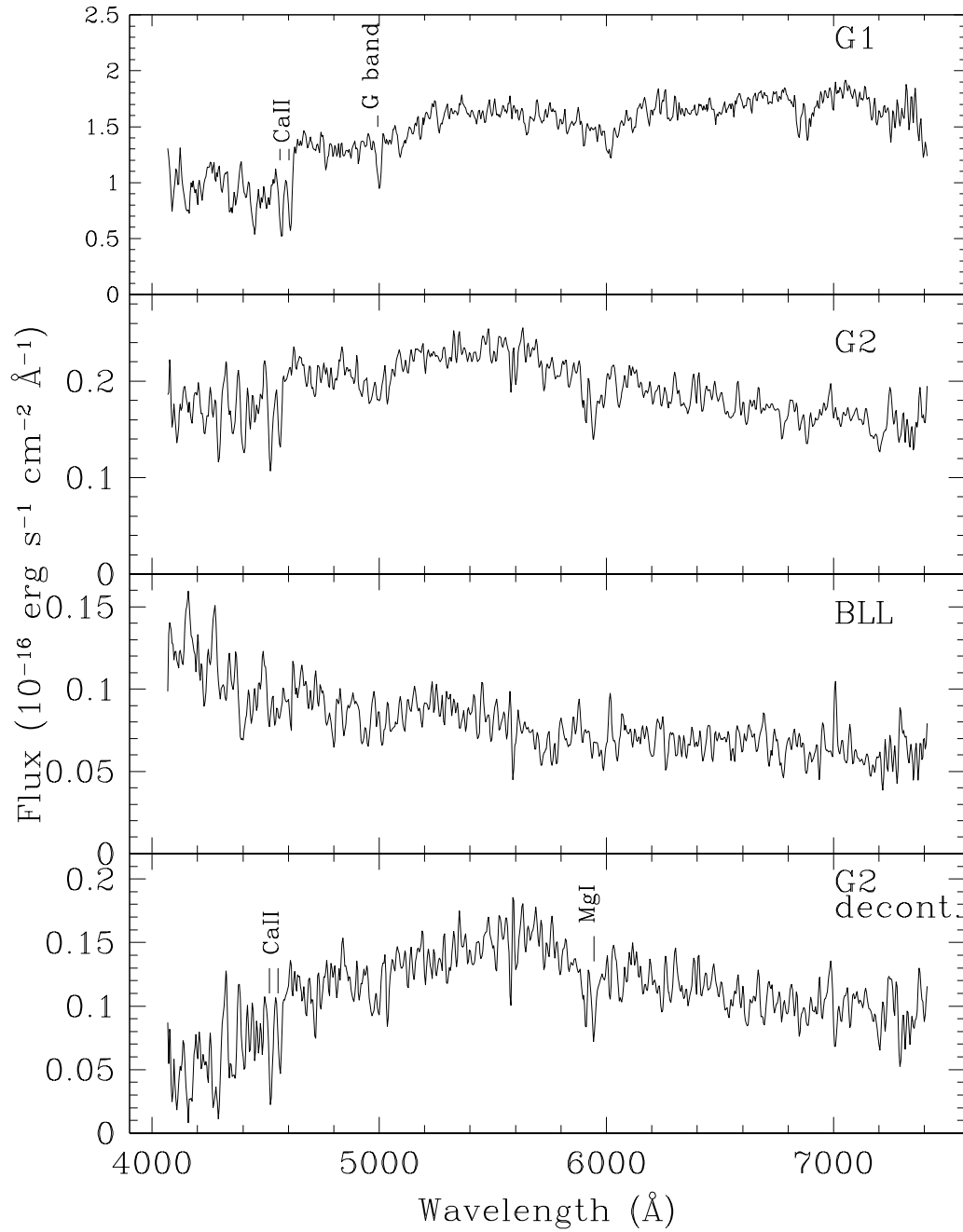


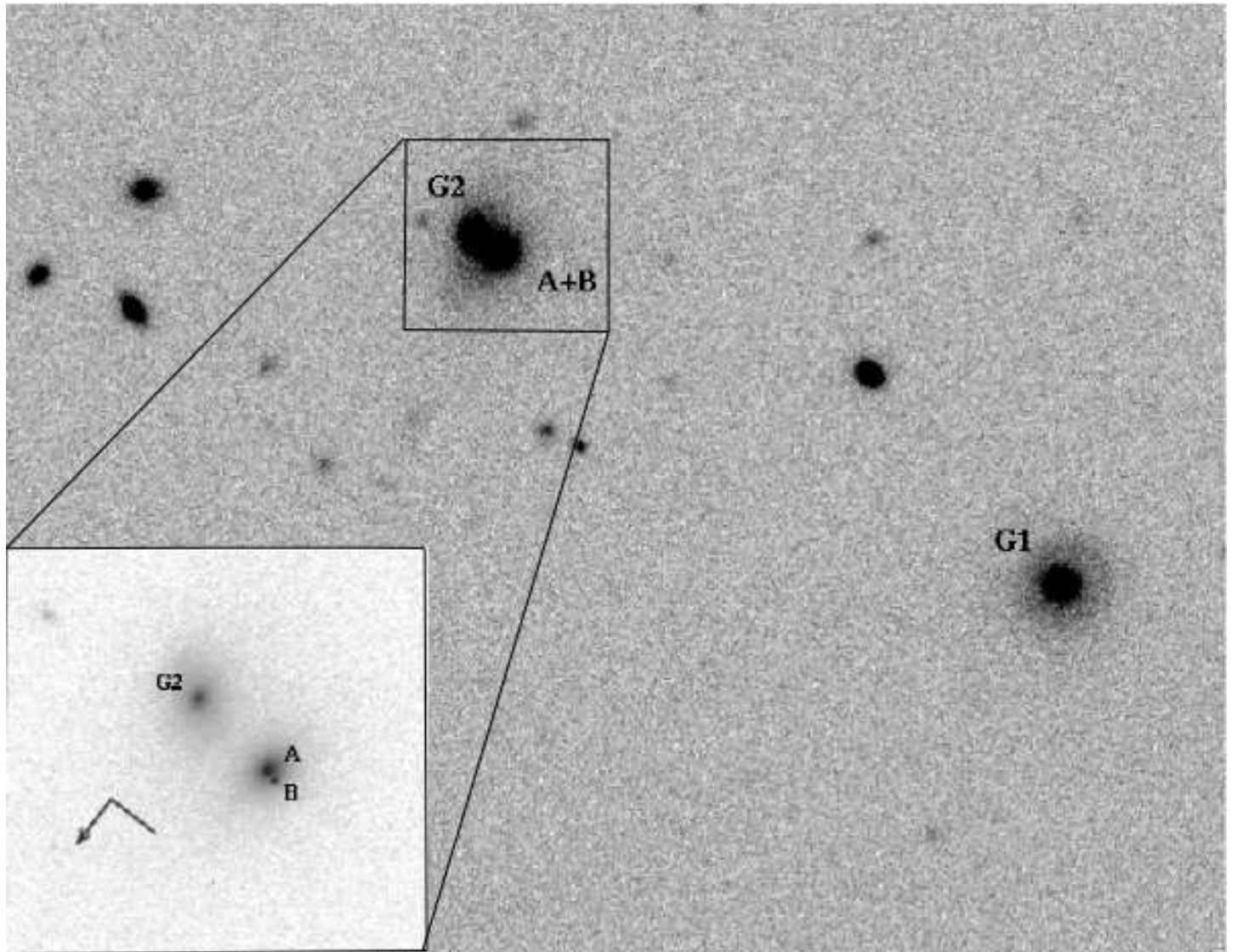
Fig. 1. continued



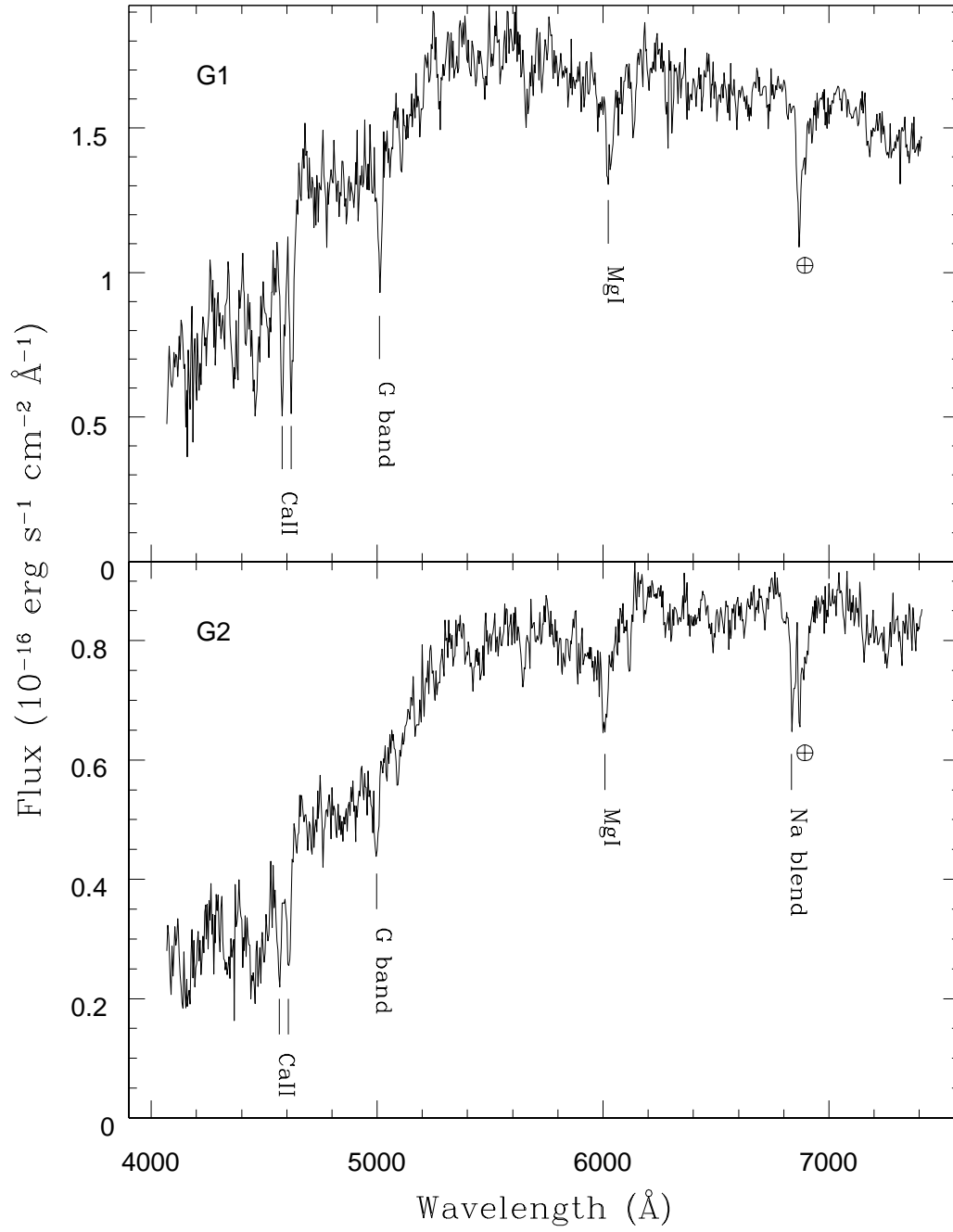
**Fig. 2.** The environment of 1H 0323+22. In the main panel (ESO 3.6m raw image, 10 s exposure), the companion galaxy G1 is labeled. The subpanel in the lower right hand corner (R-band image, adapted from Falomo (1996)) shows a higher resolution image of the BL Lac. The nucleus surrounded by the host galaxy is apparent together with the compact knot G2. The angular separation between the nucleus and G2 is  $2.6''$



**Fig. 3.** Spectra of the companion objects of 1H 0323+22. Top panel: G1; Second panel: G2 (before decontamination); Third panel: Spectrum of the BL Lac, taken with an aperture symmetric to G2; Bottom panel: G2 (decontaminated spectrum)



**Fig. 4.** The environment of 1ES 1440+122. In the main panel (R-band image taken at the NOT by R. Falomo), the locations of galaxies G1 and G2 and the nucleus (A+B) are indicated. Subpanel: HST detail of the region around the BL Lac (filter F702W image from Scarpa et al., 1999); A is the BL Lac nucleus, B is a foreground star (see Giovannini et al. (2004)). The angular separation between A and G2 is 2''.



**Fig. 5.** Spectra of the companion galaxies G1 (top) and G2 (bottom) of 1ES 1440+122